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Selecting Loblolly Pine Parents for Seed Orchards to Minimize the Cost of Producing Pulp

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ABSTRACT. Southern pine cooperative breeding programs currently emphasize genetic improvement of growth rates. When a deployment population, typically a seed orchard, is established, there is an opportunity to emphasize traits other than growth rate to maximize the profit of individual cooperators in the breeding program. We studied a Southeast Texas breeding population and developed selection indexes to optimize profits for Kraft and mechanical pulp mills. The relative economic weights for volume and wood density were 1:8.1 and 1:8.6 for Kraft and mechanical pulp mills, respectively. Choosing parents with these indexes increased expected profit per ton of dry pulp by 3.4% for both mill types. Expected gains in profit were 3.3% when parents were chosen based on wood density alone. If parents were chosen based solely on volume growth, expected gains in profit were only 0.3%—0.4%. For. Sci. 45(2): 213–216.

Additional Key Words: Kraft pulp, mechanical pulp, seed orchards, selection index, deployment population, economic weights, relative economic weights.

Southern softwood accounts for about 23% of the total growing stock in the United States, but 53% of the total softwood removals. Excluding future growth at removal rates of the late 1980s and early 1990s, there is estimated to be only an 18 yr supply of softwood available in the South (Cubbage et al. 1995). Although physical conifer availability is expected to increase at nearly 20 million m^3/yr (Hagler 1996), harvest cutbacks on public lands in the West, demographic pressures, and environmental factors threaten significant declines in southern timber supplies. Achieving the projected timber harvests without reducing growing stocks will be difficult if the forecast that manufacturing capacity will have to double over the next 25 yr to meet the worldwide demand for paper and wood products is correct (Wrist 1995). Substantial enhancements in management practices must be made to increase both harvest and product yields.

One way to increase yields per unit of land and the yields from mills is through the genetic improvement of growth rate and wood density. The efficiency of selection is enhanced by selecting for improvements in both traits concurrently with optimum economic weights for each trait (Bridgwater et al. 1983). Economic weights are the value of a unit change in a trait, for example, dollars per increase of 1 m^3 of wood/ha. Economic weights are often applied in selection as relative economic weights, the ratio of each of the economic weights to one economic weight, for ease of calculation. The accuracy of this selection method, index selection, depends on the accuracy of the economic weights for each trait. Appropriate estimates of economic weights must consider plantation establishment and management costs, harvest and transportation costs, and milling costs. Modifying growth rate and wood density influences the total cost of producing pulp and paper products at every stage of the process from forest to mill. In a landmark study, it was demonstrated that selection based on indexes which included volume, wood density, and pulp yield gave the greatest expected gains in the breeding objective, cost savings per ton of pulp produced from Eucalyptus in Portugal (Borralho et al. 1993). Furthermore, the economic weights for wood density and pulp yield were shown to be far greater than previously assumed.

Breeding programs for loblolly pine in the southern United States currently emphasize increasing growth rates (Lowe

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and van Buijtenen 1986). Including wood properties among selection criteria in breeding programs has been debated since tree improvement began in the region. This debate continues for several reasons. First, wood properties are generally more difficult and expensive to measure than survival, growth, and the impact of pests. In particular, it is very expensive and time consuming to do chemical analyses and wood fiber measurements although new methods of evaluating wood quality quickly and less expensively may reduce the costs of breeding for these traits (Chapter II in Zhang et al. 1997). Secondly, large loblolly pine tree improvement programs in the southern United States are done cooperatively among organizations that may have different product objectives. Optimizing the raw material supply for any single product through breeding implies less than optimum raw material for organizations with different end uses. Last, the raw material supply for any one organization is obtained from a variety of sources. All producers acquire raw materials from both fee and nonfee lands, and in different proportions at different times. The wood furnish may be particularly variable for pulp mills. These furnishes may be composed of chips from tops or small trees thinned from stands (low-density juvenile wood) or chips from slabs and edgings from sawmills (high-density mature wood). Wood of different densities can be separated in wood yards prior to pulping to increase uniformity, but the extent to which selection and breeding to modify wood properties can affect pulp mill furnishes depends on the proportion of wood derived from genetically improved trees.

Because of the uncertainty about how to change wood density in southern pine tree improvement programs, breeders have selected for improved growth rate and attempted to leave wood density unchanged in breeding populations (Lowe and van Buijtenen 1986). This has been possible because it is generally accepted that wood density is not strongly genetically correlated with growth traits even though there are conflicting reports in the literature (Zobel and van Buijtenen 1989, Zobel and Jett 1995). Even though wood properties are not a selection criterion in the breeding population, there is an opportunity for tree breeders to emphasize traits other than growth rate when establishing deployment populations. A deployment population is a highly selected subset of a breeding population, which is used to produce propagules for plantation establishment. In southern pines, deployment populations are usually wind-pollinated seed orchards since other methods of producing large numbers of propagules inexpensively are not well developed.

In this study we estimated economic weights for growth rate and wood density for a variety of management schemes and pulping methods currently employed by members of the Western Gulf Forest Tree Improvement Program (WGFTIP). We used the methods of Borralho et al. (1993) and examined the benefits of applying the weights when choosing parents for seed orchards. We assumed that the fiber supply for pulp mills would come entirely from genetically improved trees. If mill operators were not able to meet this assumption, our conclusions apply only to that portion of the mill supply that is obtained from such stands.

Methods and Materials

We followed the methods of Borralho et al. (1993) closely to develop economic weights. A more complete discussion of methods and assumptions may be found therein. Briefly, we assumed that each mill produces a single product and that pulp is sold at market prices. Thus, real profit can be increased only by reducing costs per unit of product. Production costs are the costs of plantation establishment (C_{PE}) and management (C_{PM}), costs of harvesting (C_H) and transport (C_T), and mill production costs (C_M). These are represented in the total cost: $C_\Sigma = C_{PE} + C_{PM} + C_H + C_T + C_M$. Profit ($Pr$) is then the difference between income (In) and costs ($Pr = In - C_\Sigma$). Wood density (DEN, kg of dry wood/m^3 green wood) and mill efficiency ($PULP$, kg of dry pulp/kg of dry wood) are used to estimate wood consumption at the mill (WC, m^3 green wood/ton of dry pulp)

$$WC = \frac{1000}{DEN \times PULP} \tag{1}$$

Incorporating WC and plantation growth rate (VOL, m^3/ha) in the profit equation gives:

$$\begin{aligned} Pr = In - [&\frac{1000}{DEN \cdot PULP \cdot VOL} \cdot \left(C_{PE} + C_{PM}\right) \\ &+ \frac{1000}{DEN \cdot PULP} \cdot \left(C_H + C_T + C_M\right)] \end{aligned} \tag{2}$$

Taking the partial derivative of Pr with respect to each trait yields the rate of change for the function for a unit change in the trait, i.e., an economic weight for that trait. The economic weights for VOL and DEN are:

$$\frac{\delta\, Pr}{\delta\, VOL} = \frac{1000}{VOL^2} \cdot \left[\frac{C_{PE} + C_{PM}}{DEN \cdot PULP}\right] \tag{3}$$

and

$$\frac{\delta\, Pr}{\delta\, DEN} = \frac{1000}{DEN^2 \cdot PULP} \cdot \left[\frac{C_{PE} + C_{PM}}{VOL} + \left(C_H + C_T + C_M\right)\right] \tag{4}$$

Values for the variable costs were available from members of the WGFTIP. These companies reported costs for three Kraft pulp mills, two groundwood mills, and one thermomechanical pulp mill (Table 1). The cost figures for the thermomechanical mill were very similar to those for the groundwood mills; thus the costs for these mills were averaged. Costs were discounted to the beginning of a rotation, which ranged from 20 to 35 yr. The economic calculations were performed by the cooperating companies using their individual, confidential rates of return. The same companies reported harvested volumes and variable costs of providing wood to the mill for six different operating scenarios. The averages of the costs for these different operational scenarios are presented in Table 2.

Table 1. Mill costs and pulp yields for two pulping processes. Costs are in 1995 U.S. dollars.

Pulp process	No. of mills	C_M (\$/m^3 of dry wood)	*PULP* (kg of dry pulp/kg of dry wood)
Kraft	3	\$53	0.51
Mechanical	3	\$123	0.93

The impact of deploying seedlings from parents selected using different criteria was explored in the Southeast Texas breeding population, one of several in the WGFTIP. Estimated breeding values for the best 20 parents in the population of 118 selected on the basis of index values, volumes, and wood densities were compared. Breeding value is a measure of the genetic value of an individual estimated directly from the mean value of its progeny when mated to a large sample of other parents. The estimated breeding values for volume were computed using the standard WGFTIP progeny test summarization procedures (Lowe and van Buijtenen 1991). This procedure incorporates a standardized performance score measured at age 5 with coefficients of genetic prediction to estimate the parental breeding value as mean annual increment at a common base age (20 yr.) Breeding values for wood density were similarly estimated. Wood density was estimated on 5-yr-old trees using the maximum moisture content method (Smith 1964). Wood density by the maximum moisture content method is the weight of the oven dry sample divided by the saturated green volume. Thus, breeding values for wood density at age 20 were estimated in units of kg dry wood/m^3 green underbark volume.

Results

Economic Weights

Values from Tables 1 and 2 were substituted into Equations (3) and (4). The value of commercial checklots in genetic tests in the WGFTIP (479 kg of dry wood/m^3 green volume) was used for wood density *(DEN)*. The relative economic weights for *VOL:DEN* ranged from 1:4.8 to 1:8.5 for Kraft mills and from 1:6.8 to 1:12 for mechanical pulp mills. Results from average values are presented in Table 3.

Deployment of Genotypes

The impact of using the estimated economic weights to select parents for seed orchards was illustrated using the Southeast Texas breeding population, one of several in the WGFTIP. This first-generation population had 118 select parents representing a range of breeding values for volume and wood density. Parental breeding values were estimated from volumes and specific gravities of progeny groups in replicated field trials. Breeding values for wood volume and wood density range from 185 to 287 m^3/ ha and 452 to 513 kg/m^3, respectively. Mean

Table 2. Average wood costs and volumes for six different operating areas. Costs are in 1995 U.S. dollars.

$C_{PE} + C_{PM}$	(\$/ha)	\$905
$C_H + C_T$	(\$/m^3)	\$17
VOL	(m^3/ha)	218

Table 3. Estimated economic values for *VOL* and *DEN* and their relative weights. Values are the cost savings in \$/tonne of dry pulp for an increase of 1 m^3/ha in green volume of wood and a 1 kg/m^3 increase in wood density. Relative weights are economic weights for *VOL* and *DEN* divided by the economic weight for *VOL*.

Pulping process	Economic weight for *VOL*	Economic weight for *DEN*	Relative economic weights (*VOL:DEN*)
Kraft	0.078	0.634	1:8.1
Mechanical	0.043	0.371	1:8.6

values for unimproved commercial checklots for southeastern Texas are 218 m^3/ha and 479 kg/m^3. First-generation selections were based primarily on parental breeding values for volume. Thus, the mean volume of the 118 selected parents (237 m^3/ha) represents an expected genetic gain of 8.7%. The average value of wood density for the population (478 kg/m^3) is slightly below the unimproved checklot mean since the correlation between breeding values (the genetic correlation) for the two traits is –0.020 (not significantly different from zero). Seed orchards are established using a more highly selected subset (usually about 20) of the parents in this breeding population. Genetic gains were calculated for seed orchards by averaging breeding values for the characters of interest without considering genetic correlations. This was appropriate because seed orchards are deployment populations established with parents whose breeding values are known. That is, all traits of interest have been measured directly in progeny populations produced by mating with a large sample of parents. Genetic correlations (correlations among breeding values) are important in breeding programs where they provide estimates of the change expected in the next generation in one trait when selection is for another. In this paper, we are addressing selection to establish deployment populations only. Averages of the best 20 parents selected based on the index, volume, and density are given in Table 4. Expected deviations from unimproved checklots differ for Kraft and mechanical processes only for the index even though the absolute values of the economic weights differ. The values for volume and density are identical because the ratios of the economic weights were so similar that the same set of 20 parents was selected by indexes for both processes.

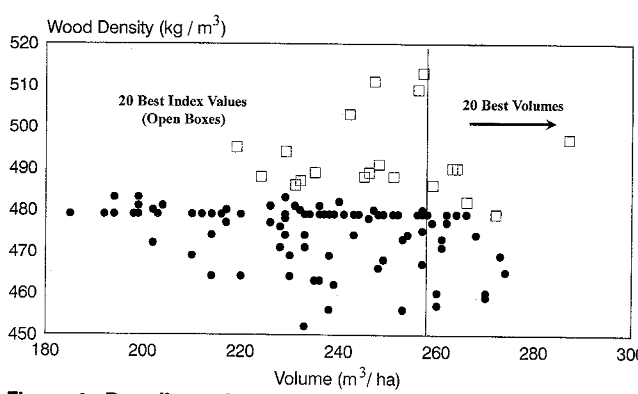

Figure 1. Breeding values for volume and wood density for 118 parents in a Southeast Texas breeding population. The parents to the right of the vertical line have the highest volumes. The 20 parents represented by open boxes have the highest values for a selection index (see text) based on volume and wood density.

Table 4. Average breeding values and expected gains for the best 20 parents selected on the basis of index values, wood volumes, and wood densities. Expected deviations from unimproved checklot differ for Kraft and mechanical processes only for the index.

	Expected deviation from unimproved check lot				Expected deviation from unimproved check lot (%)			
	Indexes ($ profit/tonne of dry pulp)							
Basis for			Volume	Density	Index			
selection	Kraft	Mech.	(m^3/ha)	(kg/m^3)	Kraft	Mech.	Volume	Density
Index	11.06	6.39	30.5	13.7	3.4	3.4	14.0	2.9
Volume	1.32	0.65	48.0	–3.8	0.4	0.3	22.0	–0.8
Density	10.78	6.24	24.7	14.0	3.3	3.3	11.3	2.9

Selection based on the index yielded the greatest expected gains in mill profitability. These gains came at the expense of lower expectations for volume gains when selection was based solely on volume (30.5 m^3/ha versus 48.0 m^3/ha). This occurred because of the greater importance of wood density in determining mill profitability for both Kraft and mechanical pulping processes (Table 3).

Selecting the parents with the highest breeding values for volume alone and for the index incorporating both volume and wood density resulted in a very different set of parents (Figure 1). The parents with the highest breeding values for volume are those to the right of the vertical line, while those with the highest breeding values for the index are indicated by the open boxes (Figure 1). Only six parents were common to the two groups.

Discussion

Our analysis indicated that the emphasis on specific gravity relative to growth should be increased when establishing seed orchards that will support regeneration programs to produce trees destined for a pulp mill. However, individual producers of wood products should consider this decision carefully for two fundamental reasons. First, our analysis assumes that pulp is the only product goal of plantation-grown wood. Thus, in our model, added growth does not add value to products except to increase the amount of pulp that can be produced from a hectare of land. This is incorrect if a manufacturer has an integrated facility that can produce higher valued solid-wood products as well as pulp or has an outside market for sawlogs. Increasing growth rate implies larger logs for a given harvest age and higher values for logs that meet minimum sawlog requirements.

Second, our analysis assumed that all of the pulp mill furnish was be from genetically improved plantations established using seedlings from parents selected using our index weights. The extent to which our findings apply depend on the proportion of the furnish derived from such plantations.

Conclusions

If seed orchard parents are selected to maximize pulp mill profitability, wood density must be given much greater weight than volume growth rate. Our results suggest that wood density should be given more than eight times the weight given to growth rate when selecting parents for seed orchards. In fact, selecting solely on the basis of wood density was nearly as efficient as selection based on an index in the study population. Wood density has a greater impact on mill profits because it affects harvesting, transportation, and milling costs ($/$m^3$) while volume growth rate affects only plantation establishment and maintenance costs ($/ha). The relative economic weights for volume growth rate and wood density were remarkably similar for two very different mill processes, Kraft and mechanical pulping.

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